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Ku-band monopulse dielectric groove lens—A new avenue in tracking class antenna

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Abstract Modern trends in radar technology very often emphasize the use of monopulse technique for airborne applications In this paper, a new avenue is paved through the design and development of a spherical-ellipsoidal grooved dielectric lens system at Ku-band for monopulse operation Besides lens, the system consists of a multimode conical corrugated feed integrated with compact clusters of four square horns and short-abrupt transitions followed by a monopulse comparator The lens so designed and developed is an excellent combination of microwave network and lens philosophy The fabrication of total system involves the usage of precision CNC and conventional machines, deft handling of the process parameters to maintain strict control on tolerances, specially for the corrugated grooves over lens surface and feed Probably for the first time grooves with definite periodicity, similar to corrugated feed, have been transferred to an outer surface of an ellipse from a cylindrical polystyrene rod Test results reveal a beautiful monopulse pattern with Gain of 25 dBi Sidelobe level of -25 dB and Null depth of the order 30 dB

The classic feature and philosophy of this type of antennas may further be explored for design and development of seeker or tracking class antenna in millimeterwaves

Keywords Monopulse, dielectric lens, antennas

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1. Introduction

Lenses are, in general, classified into two categories : Dielectric lens and Constrained lens. Risser [1], Brown [2], Collin [3], all had provided excellent review on many lens designs with their practical considerations. Analysis of any lens is normally dealt with progressive primary and secondary rays towards outer aperture. Primary rays are incident at the inner surface and reflected rays, if any, focus at a feed point. If the feed is well-matched to free space in the absence of lens, the reflection coefficient at the feed can be a minimum in the presence of lens. The situation is some what exceptional here because of reflection from the elliptic cylindrical second surface of lens. On the second surface, the direction of normal varies point to point and thus the average back scattering effect is defocused. All these reflections primarily appear as contribution to the total field half-space behind the feed with some depolarization effect. Back scattering caused by air-dielectric mismatch at any one of lens surface produce an unacceptable high input VSWR at the feed port.

2. Basic principle

The design principle of this type of lens partially impose the power conservation law constrained by well-known 'Abbe Sine' condition. The inner surface facing the feed is spherical for better impedance match due to normal incidence from a point source. When the Abbe Sine condition is imposed on the lens design, the aperture power distribution can be no longer independently specified, in other words, distribution is identical with that of feed pattern. Finally, the lens shape controls the aperture taper for a desired beam and side lobe structure.

Clarricoats and Olver [4] discussed extensively and elaborately the design principle of monopulse feed. The only new design factor introduced here is a matching step to compromise the excitations through E_{02} and HE_{21} modes for a better elevation difference pattern which is very difficult to yield and always a nightmare to the designer.

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3. Analysis

Lens geometry is shown in Figure 1. For the ease of fabrication as well as realization of hardware, let the ellipsoid

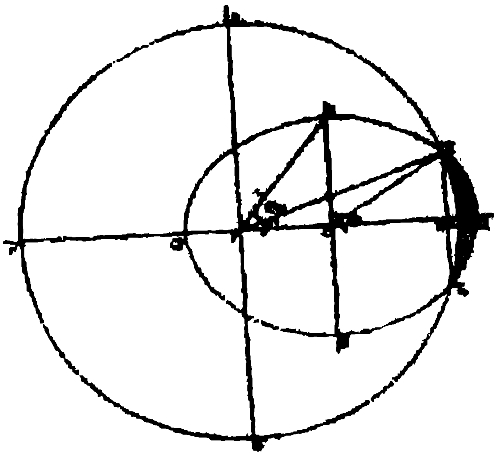

Figure 1.

be in the form of elliptic-cylinder formed by $Z = 0$ plane and its 'Director' sphere be produced by intersection of the circle $x^2 + y^2 = R^2$ with the plane $Z = 0$ such that $R^2 = a^2 + b^2$ (condition for sphere to be 'Director' one) where a and b are the semi-major and semi-minor axes of ellipse respectively Other design data considered are as follows :

Dielectric constant : $\varepsilon_r = 2.54$ for polystyrene,

Refractive index $n = \sqrt{\varepsilon_r} = 1.594$,

Eccentricity : $e = 1/n = 0.627$,

Angle subtended : $\theta_m = \cos^{-1}(1/n) = 51.137°$ at the tips of lens by Focus.

Let the guiding equation of the generating curve (elliptic) T_1T_2 be

$$r = f(n-1)/(n-\cos\theta), \tag{1}$$

where f is the distance along the axis from the focus F to T_1T_2 and $1/n$ the eccentricity of the ellipse with the origin at the focus furthest form Q.

For a given focal length, the aperture of the lens can not be larger than $2b$ and the minimum ratio of focal length to the diameter is

$$f/2b = \frac{1}{2}\sqrt{[(n+1)/(n-1)]} \tag{2}$$

which is 1.05 for polystyrene.

For a spherical lens with a point source at F, if $P(\theta)$ is the power radiated per unit solid angle in the conventional θ direction and $P(\rho)$ the corresponding power per unit area in the aperture at a distance form the axis $\rho(= r \sin\theta)$

$$\frac{P(\rho)}{P(\theta)} = \frac{\sin\theta \, d\theta}{\rho \, d\rho} \tag{3}$$

Now for an elliptic surface generated by the curve of eq. (1)

$$\frac{P(\rho)}{P(\theta)} = \frac{(n-\cos\theta)^3}{(n-1)^2 f^2 (n\cos\theta - 1)} \tag{4}$$

and the corresponding amplitude ratio

$$\frac{A(\rho)}{A(\theta)} = \sqrt{\frac{(n-\cos\theta)^3}{(n-1)^2 f^2 (n\cos\theta - 1)}}. \tag{5}$$

Plot of the amplitude ratio normalized to unity at $\theta = 0$ is shown in Figure 2. This points out the fact that the amplitude

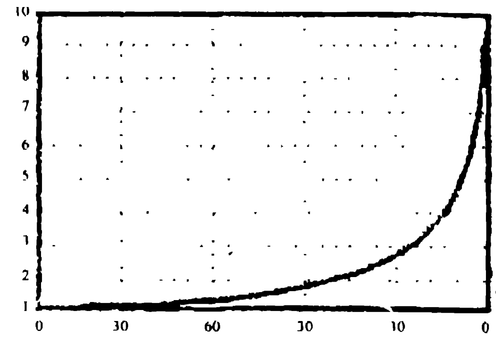

Figure 2.

in the aperture increases relative to the feed amplitude with increasing θ. This property of elliptical contour is very significant of microwave network.

4. Hardware and fabrication

The hardware of the system consists of lens, conical corrugated feed, square horns, transitions and monopulse comparator

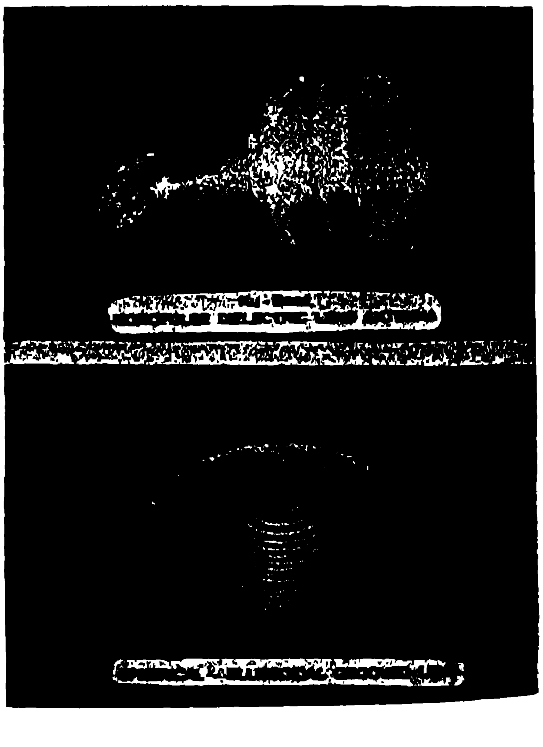

Figure 3.

Of these, the fabrication of lens, the corrugated feed are very critical and require deft handling. These have been realised by the combination of precision CNC/conventional machines. The process parameters have been carefully planned and executed to attain strict control on the tolerances, specially for the corrugations which were machined over the lens surface and the feed. Special and unique tools for machining the grooves were planned and fabricated to attain the groove details. CNC machining was done with strict control of process parameters such as feed, rpm of the cutting tool and depth of cut. It involved process planning, tooling, fixturing commensurate with skill, precision and patience to realize the hardware. Figure 3, depicts the integrated system of dielectric lens antenna as well as the top surface of lens with critical grooves

5. Results

Integrated lens system is evaluated and optimized in indoor "Compact Antenna Test facility". Figure 4 depicts the excellent performance of the monopulse antenna. Results are summarized in Table 1.

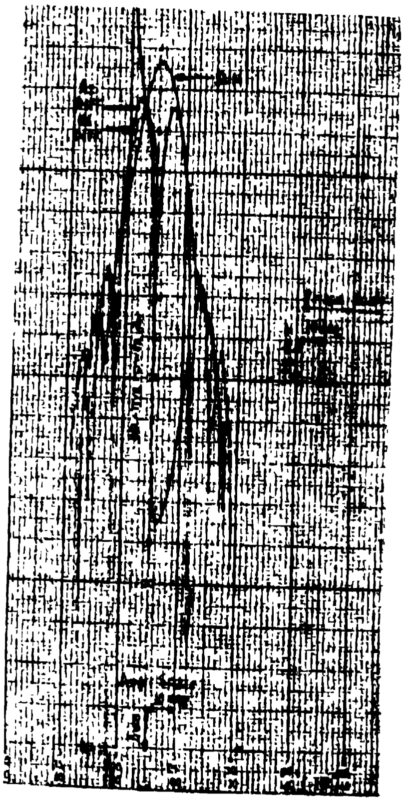

Figure 4.

Table 1.

	Half-Power Beam Width (deg)	Side lobe level (dB)	Gain (dBi)
SUM	7.5	-25.2	25.4
	Peak level (dB down)	Peak Asymmetry (dB)	Null Depth (dBi)
AZ DIFF	3.2	1.2	30.0
EL DIFF	4.0	0.6	35.0

6. Conclusions

The approach for using a dielectric lens for monopulse operation can open a new avenue. Also, transferring the periodic grooves on an elliptical surface is not only very difficult but also of innovative in nature. Moreover, dielectric lens antenna occupy less space than the conventional antenna at this frequency band. So, this type of antenna is having a very good potential to be used as a seeker or tracking antenna. The philosophy, described here, can be extended to design and develop of this class antenna for millimeter wave too

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